

**TITLE**

**DRIVING CIRCUIT FOR OPTICAL MODULATOR**

**BACKGROUND OF THE INVENTION**

**Field of the Invention**

5 The present invention relates in general to a driving circuit for an optical modulator including a cascode of electrical elements, wherein output voltage is uniformly shared between the transistors of the cascode electrical elements to increase the operating range of the output voltage.

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**Description of the Related Art**

Optical transmission systems with high capacity are widely implemented. To meet requirements of high speed and long distance communication, optical transmitter employing continuous-wave 15 (CW) laser diode operating with a high-speed optical modulator is crucial. The driving circuit of the optical modulator is typically manufactured by an integrated circuit process with high breakdown voltage to output high voltage between about 3~10 volts, thus increasing manufacturing cost. Hence, a method for 20 forming the high-voltage driver with a low-voltage integrated circuit process is necessary.

FIG. 1 is a circuit diagram of a conventional driving circuit. The conventional driving circuit comprises transistors 10 and 11 and a current source  $I_m$ . Current source  $I_m$  is directed 25 to flow through the transistors 10 or 11 toward the output terminals  $V_{O1}$  or  $V_{O2}$  by the differential signals respectively input to the input terminals  $S_1$  and  $S_2$ . The output voltages are output completely across the transistor 10 or 11. Thus, the

output voltage value is limited by the breakdown characteristics of the transistors 10 and 11.

FIG. 2 is a circuit diagram of a conventional driving circuit comprising a cascode of transistors. The high voltage output terminal of the driving circuit comprises a plurality of transistors, wherein the second transistor 12, the third transistor 13, the fourth transistor 14 and the fifth transistor 15 comprise a cascode structure for sharing the high output voltage. The driving circuit however requires an extra source-follower to couple partial output voltage to the gate of the third transistor 13. Thus, power consumption is increased and the increment of the gate delay deteriorates the high frequency output characteristics.

To solve the disadvantages of the conventional driving circuit, the present invention provides a driving circuit for outputting high voltage.

#### **SUMMARY OF THE INVENTION**

The object of the present invention is thus to provide a driving circuit for an optical modulator including a cascode of output structures, wherein output voltage is uniformly shared between the transistors of the cascode structures to increase operating range of the output voltage.

In addition, output voltage of the driving circuit is uniformly shared between the cascode transistors by using feedback voltage provided by passive components, such as resistors and capacitors. Thus, a damage to the output transistors due to output voltage exceeding a voltage tolerance range is prevented. Additionally, output voltage is doubled by

the cascode of output stages without influencing the circuit operation.

Moreover, a base control signal of the upper cascode transistors is generated by a gain unit and the value of the high 5 frequency signal fed back from the output terminal is controlled by adjusting the capacitance ratio of two capacitors to obtain an optimized output waveform.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

10 The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings, given by way of illustration only and thus not intended to be limitative of the present invention.

15 FIG. 1 is a circuit diagram of a conventional driving circuit.

FIG. 2 is a circuit diagram of another conventional driving circuit.

FIG. 3 is a circuit diagram of a driving circuit according to first embodiment of the present invention.

20 FIG. 4 is a circuit diagram of a driving circuit according to second embodiment of the present invention.

FIG. 5 is a circuit diagram of a driving circuit according to third embodiment of the present invention.

25 FIG. 6 is a circuit diagram of a driving circuit according to fourth embodiment of the present invention.

#### **DETAILED DESCRIPTION OF THE INVENTION**

FIG. 3 is a circuit diagram of a driving circuit according to first embodiment of the present invention.

The driving circuit according to the first embodiment of the present invention comprises input terminals S1 and S2. First transistor T1 is connected to input terminal S1, and second transistor T2 is connected to input terminal S2. In addition, 5 the emitters of first transistor T1 and second transistor T2 are connected and are further connected to ground through current source  $I_m$ .

Additionally, first transistor T1 is connected to third transistor T3 in serial, and the connection point of first 10 transistor T1 and third transistor T3 is connected to first current source I1. Second transistor T2 is connected to fourth transistor T4 in serial, and the connection point of second transistor T2 and fourth transistor T4 is connected to second current source I2. First current source I1 and second current 15 source I2 respectively provide bias current of third transistor T3 and fourth transistor T4 to decrease switching time of transistors and avoid output waveform distortion.

In addition, third transistor T3 connected to first transistor T1 and first current source I1 is further connected 20 to first feedback circuit 20. First feedback circuit 20 comprises a low frequency feedback circuit and a high frequency feedback circuit. The low frequency feedback circuit comprises a first resistor R1 and a second resistor R2. A feedback signal with lower frequency is controlled by the ratio of first resistor R1 to 25 second resistor R2. The high frequency feedback circuit comprises an equivalent collector-base capacitor Ccb1 of third transistor T3 and first capacitor C1. A feedback signal with higher frequency is controlled by the ratio of collector-base capacitor Ccb1 to first capacitor C1.

Fourth transistor T4 connected to second transistor T2 and second current source I2 is further connected to second feedback circuit 21. Second feedback circuit 21 comprises a low frequency feedback circuit and a high frequency feedback circuit as first 5 feedback circuit 20. The low frequency feedback circuit comprises a third resistor R3 and a fourth resistor R4. A feedback signal with lower frequency is controlled by the ratio of third resistor R3 to fourth resistor R4. The high frequency feedback circuit comprises an equivalent collector-base capacitor Ccb2 of 10 fourth transistor T4 and second capacitor C2. A feedback signal with higher frequency is controlled by the ratio of collector-base capacitor Ccb2 to second capacitor C2. Second resistor R2 and fourth resistor R4 are all connected to reference voltage VT1. Additionally, the cascode resistors of feedback 15 circuits 20 and 21 can also act as back termination resistors to improve impedance matching.

The principal design spirit of the present invention is not limited by the first embodiment. Thus, other high voltage driving circuits with a cascode of structures are provided by other 20 embodiments.

FIG. 4 is a circuit diagram of a driving circuit according to second embodiment of the present invention. The differences between first and second embodiments are described in the following. Third transistor T3 is further connected to fifth 25 transistor T5 to form a cascode of structures with more stages.

Fifth transistor T5 connected to third transistor T3 is further connected to third feedback circuit 22. Third feedback circuit 22 comprises a low frequency feedback circuit and a high frequency feedback circuit as feedback circuits 20 and 21. A 30 feedback signal with lower frequency is controlled by the ratio

of fifth resistor R5 to sixth resistor R6, and a feedback signal with higher frequency is controlled by the ratio of equivalent collector-base capacitor Ccb3 of fifth transistor T5 to third capacitor C3.

5       Fourth transistor T4 is further connected to sixth transistor T6 to form a cascode of structures with more stages. Sixth transistor T6 connected to fourth transistor T4 is further connected to fourth feedback circuit 23 comprising a low frequency feedback circuit and a high frequency feedback circuit.

10      A feedback signal with lower frequency is controlled by the ratio of seventh resistor R7 to eighth resistor R8, and a feedback signal with higher frequency is controlled by the ratio of equivalent collector-base capacitor Ccb4 of sixth transistor T6 to fourth capacitor C4.

15      Sixth resistor R6 and eighth resistor R8 are all connected to reference voltage VT2. The cascode resistors of feedback circuits 22 and 23 further act as back termination resistors to improve impedance matching.

20      The feature of the second embodiment of the present invention is the triple output voltage using a cascode of structures according to the design spirit of the present invention.

25      FIG. 5 is a circuit diagram of a driving circuit according to third embodiment of the present invention. The difference between second and third embodiments is first resistor R1 of first feedback circuit 20 and third resistor R3 of second feedback circuit 21 are respectively connected to output terminals Vo1 and Vo2. Thus, low frequency feedback circuits of third feedback circuit 22 and first feedback circuit 20 are connected, and low 30 frequency feedback circuits of fourth feedback circuit 23 and

second feedback circuit 21 are connected. Other circuitry connections and operation are the same as in the second embodiment.

Moreover, the cascode resistors of feedback circuit 20 and 5 21 in first embodiment can be replaced by a voltage gain circuit.

FIG. 6 is a circuit diagram of a driving circuit according to fourth embodiment of the present invention. The emitters of first transistor T1 and second transistor T2 are connected to a first reference current source 110. Additionally, first 10 transistor T1 is connected to first input terminal S1 and first resistor R1, second transistor T2 is connected to second input terminal S2 and second resistor R2, and resistors R1 and R2 are respectively connected to reference voltage VT1.

Input terminals S1 and S2 are further connected to third 15 resistor T3 and fourth resistor T4. The emitters of transistors T3 and T4 are connected to a second reference current source 111. In addition, third transistor T3 is connected to first current source I1 and connected to fifth transistor T5 in serial, and fourth transistor T4 is connected to second current source I2 and 20 connected to sixth transistor T6 in serial. Fifth transistor T5 is connected to first current I1, and first current I1 is connected to the connection point of third transistor T3 and fifth transistor T5. The base of fifth transistor T5 is connected to first capacitor C1 and first resistor R1. A first high frequency 25 feedback circuit comprises collector-base capacitor Ccb1 of fifth transistor T5 and first capacitor C1. In addition, sixth transistor T6 is connected to second current source I2, and second current I2 is connected to the connection point of fourth transistor T4 and sixth transistor T6. The base of sixth 30 transistor T6 is connected to second capacitor C2 and second

resistor R2. A second high frequency feedback circuit comprises collector-base capacitor Ccb2 of sixth transistor T6 and second capacitor C2.

Similar with first embodiment, the high frequency signal fed 5 back from the output terminal is controlled by adjusting the capacitance ratio of first capacitor C1 and collector-base capacitor Ccb1, and that of second capacitor C2 and collector-base capacitor Ccb2 to obtain an optimized output waveform. In addition, resistor R1 and R2 comprise a resistor 10 set connected to reference voltage VT1.

In the fourth embodiment, resistors R1, R2, R3, and R4 are replaced by a voltage gain circuit to provide a low frequency base control signal, hence output voltage is shared between the transistors of the cascode structures.

15 According to the embodiments of the present invention, output voltage is uniformly shared and high output voltage is easily obtained by the cascode output stage comprising a plurality of transistors.

20 The foregoing description of the invention has been presented for purposes of illustration and description. Obvious modifications or variations are possible in light of the above teaching. The embodiments were chosen and described to provide the best illustration of the principles of this invention and its 25 practical application to thereby enable those skilled in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the present invention as determined by the appended claims when

interpreted in accordance with the breadth to which they are fairly, legally, and equitably entitled.